EDGEWOOD
CHEMICAL BIOLOGICAL CENTER
U.S. ARMY SOLDIER AND BIOLOGICAL CHEMICAL COMMAND

ECBC-TR-133

SUMMARY REPORT FOR USE OF POSITIVE PRESSURE VENTILATION (PPV) FANS TO REDUCE THE HAZARDS OF ENTERING CHEMICALLY CONTAMINATED BUILDINGS

PPV Guidelines

- The use of PPV fans dramatically decreases the interior chemical agent vapor concentration of structures. For example, PPV fans can reduce the vapor concentration by 50%-70% during the first 10 minutes of use.
- PPV significantly increases the first responders' protection above and beyond the adequate protection provided by standard turnout gear with SCBA when rescuing known live victims.
- Before using PPV, consider the downwind hazard for unprotected people.
- Bigger fans are better. Two fans are better than one. Tilting the fan improves performance.
- Use Negative Pressure Ventilation (NPV) at buildings where victims are present in closed interior rooms (doors closed).

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January 2001

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Chemical Team

CUM SCIENTIA DEFENDIMUS

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Aberdeen Proving Ground, MD 21010-5424

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REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave Blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	2001 January	Final; 98 May – 99 Sep

4. TITLE AND SUBTITLE
Summary Report for Use of Positive Pressure Ventilation (PPV) Fans to Reduce the Hazards of Entering Chemically Contaminated Buildings

5. FUNDING NUMBERS
NONE

6. AUTHOR(S)
Arca, Victor J.; Marshall, Stephen M.; Lake, William A.; and Fedele, Paul D.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
DIR, ECBC, ATTN: AMSSB-REN-HD-DI, APG, MD 21010-5424

8. PERFORMING ORGANIZATION REPORT NUMBER
ECBC–TR-133

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
DIR, ECBC,* ATTN: AMSSB-REN-HD-DI, APG, MD 21010-5424

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
*When this study started, the U.S. Army Edgewood Chemical Biological Center was known as the U.S. Army Edgewood Research, Development and Engineering Center (ERDEC).

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
Firefighters have used Positive Pressure Ventilation (PPV) fans to remove smoke from buildings before entry for rescue operations. A study was conducted to determine their effectiveness in removing chemical vapors from a building to afford quick rescue in the event of a terrorist bomb that employed chemical warfare agents. The testing was conducted in two phases. The first phase examined the ventilation rates of the building in natural and forced air (with the PPV fans) modes to determine the improvement in ventilation when PPV fans were used, and to determine how much vapor can be purged from a building within the first 10 minutes of PPV fan use. The second phase examined a mock rescue scenario in the same building by filling it with methyl salicylate and measuring the Physiological Protective Dosage Factor (PPDF) that firefighters received while performing the rescue mission. This testing was performed according to standard Man-in-Simulant Test (MIST) procedures. Previous MIST testing of firefighter gear was used as a baseline to determine the increased protection obtained by using PPV fans.

14. SUBJECT TERMS

Chemical protective suits	Positive pressure ventilation	MIST
Self-taped quick fix	Man-in-Simulant Testing	MRED
Body region hazard analysis	Methyl salicylate	PSD
Physiological protective dosage factor	Bunker gear	PPV

15. NUMBER OF PAGES
41

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

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PREFACE

The work described in this report was funded by the Domestic Preparedness Program. This work started in May 1998 and was completed in September 1999.

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Acknowledgments

The authors gratefully acknowledge the help and assistance of the firefighters from Montgomery County Fire and Rescue Service and Baltimore County Fire Department who contributed their time, experience, and equipment to assist us completing the technical testing. Their technical assistance in providing PPV fan guidance, training, literature, and test subjects for Phase II of the testing was invaluable.

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Summary Report for Use of Positive Pressure Ventilation (PPV) Fans To Reduce the Hazards of Entering Chemically Contaminated Buildings

ARE YOU PROTECTED?

BETTER SAFE THAN SORRY

PPV Guidelines

- The use of PPV fans dramatically decreases the interior chemical agent vapor concentration of structures. For example, PPV fans can reduce the vapor concentration by 50%-70% during the first 10 minutes of use.
- PPV significantly increases the first responders' protection above and beyond the adequate protection provided by standard turnout gear with SCBA when rescuing known live victims.
- Before using PPV, consider the downwind hazard for unprotected people.
- Bigger fans are better. Two fans are better than one. Tilting the fan improves performance.
- Use Negative Pressure Ventilation (NPV) at buildings where victims are present in closed interior rooms (doors closed).

1. INTRODUCTION AND BACKGROUND

This report contains information concerning testing of Positive Pressure Ventilation (PPV) fans for use by emergency first responders in the event of a terrorist attack that employs Chemical Warfare Agents (CWA). For easy dissemination, this report is available at the following web-site: http://www.nbc-prepare.org. PPV fans are common equipment to many firefighters. During fire fighting operations, PPV fans are used to clear smoke from burning buildings, so that quick rescues can be performed in these buildings. PPV fan use is common in many fire departments. Methods of using PPV fans in fire fighting are well documented.

At Aberdeen Proving Ground, the Domestic Preparedness (DP) program has investigated using PPV fans to reduce the concentration of CWA (or other HAZMAT vapors) in vapor-contaminated buildings. A scientific study was undertaken to measure and document how PPV fans reduce indoor vapor concentration, in a specific building. This information has been used to develop recommendations for using PPV fans to reduce indoor agent concentration, before fire and rescue personnel enter a vapor-contaminated building. Reducing the vapor concentration inside a contaminated building will reduce the hazard faced by rescue personnel.

Although using PPV fans can reduce hazards, rescue personnel should wear Self-Contained Breathing Apparatus (SCBA) and Bunker Gear for protection during rescue operations. Reducing the vapor concentrations in the building will reduce the skin absorption and respiratory hazards faced by rescue personnel, but personal protective equipment still must be used in the suspected presence of CWA.

The Edgewood Chemical and Biological Center (ECBC) completed this work as a special task under the DP program. This work evaluates the increased protection provided to firefighters and emergency rescue personnel, when they use PPV fans to reduce the concentration in buildings. Although the measurements reflect vapor reduction in a specific building, recommendations have been generalized to apply broadly to indoor vapor contamination. This report outlines the testing and shows the benefits of using these fans in instances of chemical vapor contamination inside buildings.

The DP program was formed under the 1996 Nunn-Lugar-Domenici law to provide expertise to first responders preparing to deal with potential chemical or biological terrorist attacks. Initial testing, conducted at the Edgewood Man In Simulant Test (MIST) Facility, examined the protection against CWA provided by firefighter personal protective clothing and equipment. The Firefighter Protective Ensemble (FFPE) examined consists of Bunker Gear with SCBA. Testing at the Edgewood MIST Facility determined the Overall Physiological Protective Dosage Factor (PPDF) of the Bunker Gear ensemble with SCBA. The Overall PPDF is determined by wearing the suit inside a chemical vapor environment and measuring the ratio of the amount of vapor that would be absorbed by the body, without the suit, to the amount of vapor that is absorbed by the body, while using the suit. Absorption occurring with no body protection was previously determined. Absorption occurring under the suit is measured with absorptive samplers placed in several locations on the body. The absorption ratios from the different body locations are weighted, according to the sensitivity of the skin at each body region, and combined to determine the overall PPDF.

Results of the initial MIST testing of Bunker Gear with SCBA are documented in a report[1] prepared by the U.S. Army Soldier Biological and Chemical Command (SBCCOM). This report is entitled "Guidelines for Incident Commanders' Use of Firefighter Protective Ensemble (FFPE) with Self-Contained Breathing Apparatus (SCBA) for Rescue Operations During a Terrorist Chemical Agent Incident." This referenced report is not only a companion report to this PPV report, but also provides rescue stay times for standard turnout gear and for several Quick-Fixes (i.e., duct taping openings such as wrists, ankles, etc.) applied to standard turnout gear. The PPV fan would be set in place while other rescue personnel are suiting up and applying Quick-

Fixes (i.e., duct-taping openings at wrists, ankles, fly, and waist). Standard Bunker Gear and SCBA should be worn while setting the PPV in place. The initial testing showed that the Bunker Gear with SCBA provides enough protection for quick rescue of surviving victims in areas where CWA are present. PPV applications are considered as an additional way of reducing risks associated with a quick rescue in chemical contamination.

This PPV testing evaluates the increased protection firefighters receive from using Bunker Gear with SCBA, to provide personal protection, and PPV fans, to lower the chemical concentration during quick rescue operations. This testing determines the "Combined PPV and Bunker Gear Physiological Protective Dosage Factor (PPDF)" that the firefighters receive by using PPV fans and taped Bunker Gear with SCBA. Improvements due solely to the use of PPV fans are determined by comparing the combined-equipment PPDF to the MIST PPDF, in which taped Bunker Gear with SCBA was evaluated without PPV.

PPV procedures for smoke removal are explained briefly. At the building, firefighters start the PPV fan. They open the main door leading into the building and direct the flow of air into the door. Fans are generally placed a distance of six to nine feet in front of the door. Streamers are taped around the edge of the door and the direction of the fan is adjusted so that all streamers show flow directed into the building. If streamers indicate flow out of the building, the fan may be moved backward or tilted upward, to more fully cover the door opening with the airflow from the fan. A window or door is then opened (or window broken/door knocked down) at the opposite end of the building to create an exit for the smoke.

WARNING

Prior to using PPV, firefighters must ensure that there are no unprotected people at the door, window, or other opening selected as the PPV exit point. If there are unprotected people at the exit, or downwind, they must be evacuated before PPV is employed. When unprotected people can not be moved from the exit point, or from the area immediately downwind of the exit point, it may be possible to select an alternate exit point, and still safely employ PPV fans.

NOTE: RESPIRATORY PROTECTION (SCBA) SHOULD ALWAYS BE USED AT A SCENE WHERE CHEMICAL CONTAMINATION IS SUSPECTED.

Using PPV fans for purging vapors from buildings has certain limitations for its safe and effective use. The use of PPV fans can force the agent to spread to other zones of a building. For example, when the agent has been released in the lobby of a multi-story building, PPV applications may spread agent to upper floors of the building. If occupants have not been evacuated from upper floors, applying PPV could put these people at risk. Similar difficulties can be encountered when PPV fans are used in fighting fires and for smoke removal.

In such chemical incidents, negative pressure ventilation may be preferable, if the intent is not to create a reduced-concentration corridor for first responder entry. During testing, it was found that negative pressure ventilation usually was just as efficient as positive pressure ventilation and, in one case, slightly more efficient.

Dealing with chemical hazards can present complex and occasionally conflicting problems. The goal of this study is to examine the use of PPV fans in clearing vapor from a

building, and determine general guidance on how PPV fans can be best employed to help deal with an emergency situation involving the airborne release of CWA materials. This study did not address CWA vapors in combination with a simultaneous fire. Fire/smoke was beyond the scope of this test effort. The main objectives of this study, and how each was addressed, are as follows:

1. To measure the reduction in concentration inside a typical building structure when different PPV fan configurations are used. Measurement of the reduction during the first ten minutes of operation was performed.

2. To determine the increase in the ventilation rate of the building when the different PPV fans are used. Building ventilation rates were measured with no PPV fans and when different PPV fans were used.

3. To determine if agent will be forced into other "closed" rooms in the building during use of the PPV fans and to measure the infiltration rates. Agent concentration was monitored in "closed" rooms within the main building structure.

4. To determine if excessive amounts of carbon monoxide (CO) are produced inside the building when gasoline-powered PPV fans are used. Carbon monoxide levels were monitored inside the building while gasoline-powered PPV fans were being used.

5. To measure increases in firefighter protection produced by using PPV fans at buildings contaminated with chemicals. MIST methods were used to directly measure firefighter protection.

2. SCOPE OF TESTING

This testing was conducted in two main phases. Phase 1 examined the ventilation rates of a building in both the natural (without PPV) and forced air environments with PPV. The difference between the natural and forced ventilation was used to determine the improvement to the ventilation rate from using the PPV fans. Phase 2 examined the use of the PPV fans in the same building during a live-rescue mission scenario. Standard MIST testing was used in this phase to determine the increased protection the firefighters received from using the PPV fans in addition to the protection they received from the Bunker Gear (i.e., the "Combined PPV/Bunker Gear PPDF"). Additional testing was also performed (during the ventilation testing) to evaluate whether contamination was transferred to closed interior rooms when PPV fans were used; this testing was conducted using fans in the positive and negative pressure ventilation modes. One final set of tests was also conducted with a gasoline-powered fan to measure how much Carbon Monoxide (CO) was produced inside the building, to determine victim exposure.

2.1 Scope of Phase 1 Ventilation Rate Testing.

The first portion of this project examined the use of PPV fans through scientific testing to remove chemical contamination from a typical building structure. Different sizes and configurations of fans were used in this testing to include the most commonly used PPV fans (16-

inch electric and 20-inch gas) along with some larger fans and series combinations with multiple fans. The ventilation rates of the building were determined from the data obtained in the chemical removal tests for both the natural (without PPV) and forced air (using PPV fans) environments. Evaluation of the protection offered through use of the different PPV fan combinations in Phase 1 was determined by making a direct comparison of the difference in ventilation rates between the natural and the forced (use of PPV) rates.

In Phase 1, the tracer gas, Sulfur HexaFluoride (SF_6), was used at an initial concentration of 100 parts per million (ppm). The concentration of SF_6 during the use of the PPV fans was measured until the level fell below 10 ppm. Eight Miniature InfraRed Gas Analysers (MIRAN®) were used to monitor the tracer gas at six locations inside the building and in two interior room locations (rooms 2 and 4). The building dimensions are shown in Figure 1. The six locations for monitoring in the building and the location of interior rooms are shown in Figure 2 below.

The fans selected and used in this testing included both gasoline and electrically powered engines. Several different sizes of the PPV fans ranging from 16-inch to 30-inch diameter were also used. A complete list of the fans used during Phase I testing and their specifications is included below.

- 16-inch Electric, SuperVac Model P164S, rated flow: 5200 cfm
- 24-inch Electric, SuperVac Model P244S, rated flow: 10800 cfm
- 20-inch Gasoline, SuperVac Model 720G4, rated flow: 16895 cfm
- 30-inch Gasoline, SuperVac Model 730G4, rated flow: 26734 cfm

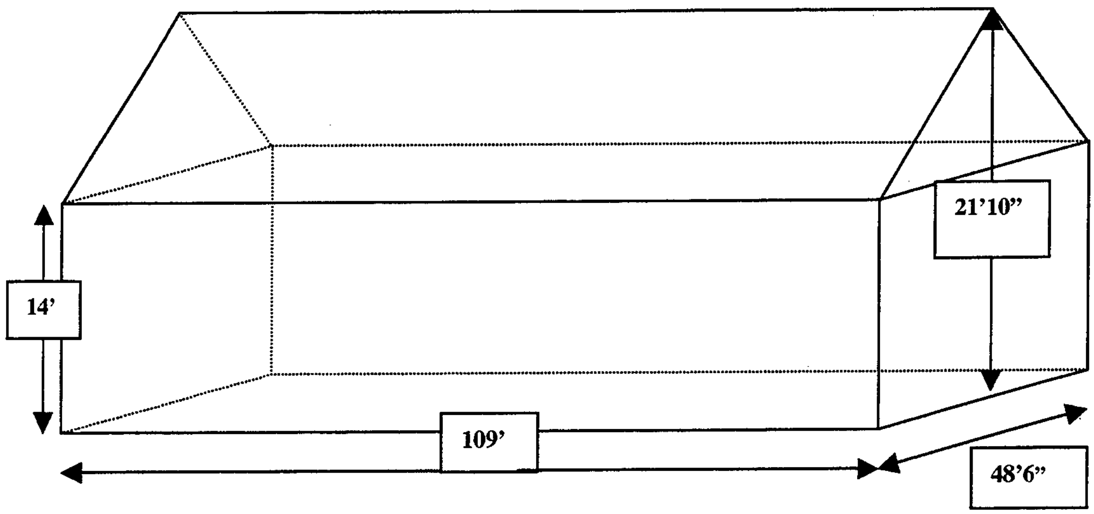

Figure 1. Dimensions of Building E5840.

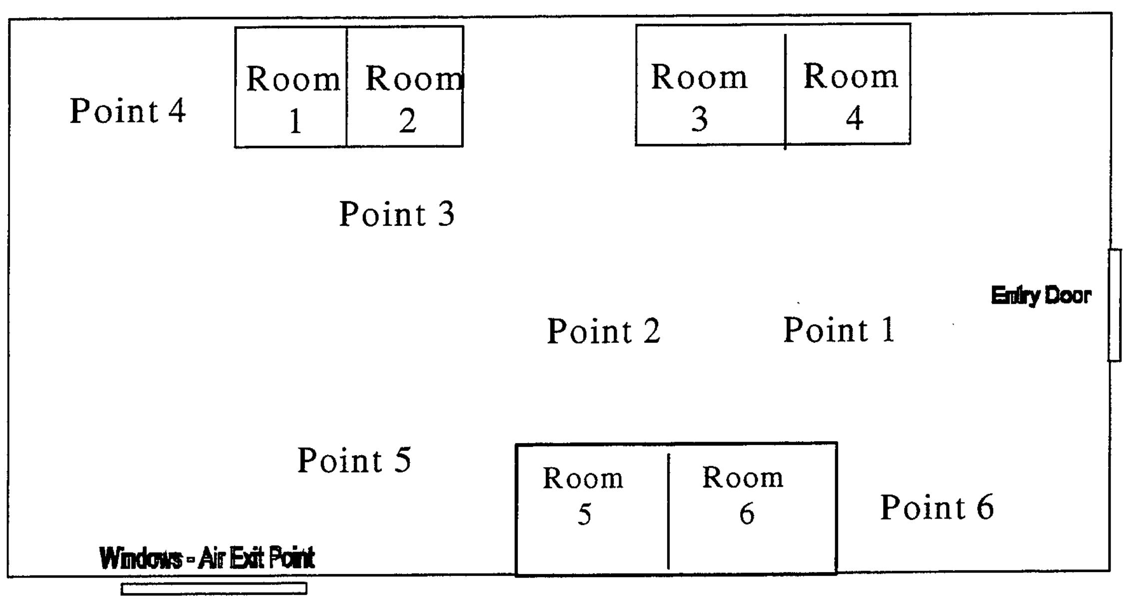

Figure 2. Floor Layout and Monitoring Locations in Building E5840

The different sizes of fans used allowed for a comparison of the range of PPV fans that are most commonly used and/or are available in the firefighter industry. A complete list of the fan combinations used in Phase 1 and the number of trials conducted per fan configuration is listed in Table 1.

Table 1. **Fan Configurations Used In Ventilation Rate Testing.**

Figure	Test Series	Fan Configuration Used	Trials Performed
3	1	Two 16-inch Electric Fans Stacked at 10' 4" from door; positive pressure	3
4	2	One 20-inch Gasoline Fan at 9' from door; positive pressure	3
5	3	One 30-inch Gasoline Fan at 9' from door; positive pressure	2
6	4	Two 20-inch Gasoline Fans in Series, 3' 6" and 9' from door; positive pressure	3
7	5	One 24-inch Electric Fan at 9' from door; positive pressure	3
8	6	One 20-inch Gasoline Fan at 5' from door, tilted at 20°; positive pressure	2
9	7	Two 20-inch Gasoline Fans in Series, first fan tilted at 20°, 5' from door, Second fan (not tilted) at 9' from door; positive pressure	3
10	8	One 24-inch Electric Fan at 4' from door; negative pressure	3
11	9	One 20-inch Gasoline Fan at 4' from door, tilted at 20°; negative pressure	3

Photographs of each of the PPV fan configurations listed in Table 1 are shown below in Figures 3 through 11. The Figures are arranged numerically to correspond to the PPV fan configurations listed above (i.e., Figure 3 is Test Series 1, Figure 4 is Test Series 2, Figure 5 is Test Series 3, etc.).

2.2 Scope of Phase 2 Live Rescue Mission Test.

The testing conducted in Phase 2 examined the use of the PPV fans in the building during a rescue mission scenario in which firefighters used the fans to clear out chemical simulant vapors before entering the building. Evaluation of the protection offered the firefighters in Phase 2 was determined by measurement of the Combined PPV/Bunker Gear Physiological Protective Dosage Factor (PPDF) of the taped suit ensemble worn by each firefighter using standard MIST procedures. To provide a baseline, a single test was conducted without using the PPV fans, to evaluate the protection offered without PPV fan use. All test results were scored according to this baseline, to determine the improvement.

Text continues on page 23.

Figure 3. Test Series 1: Two 16" Electric Fans, Stacked

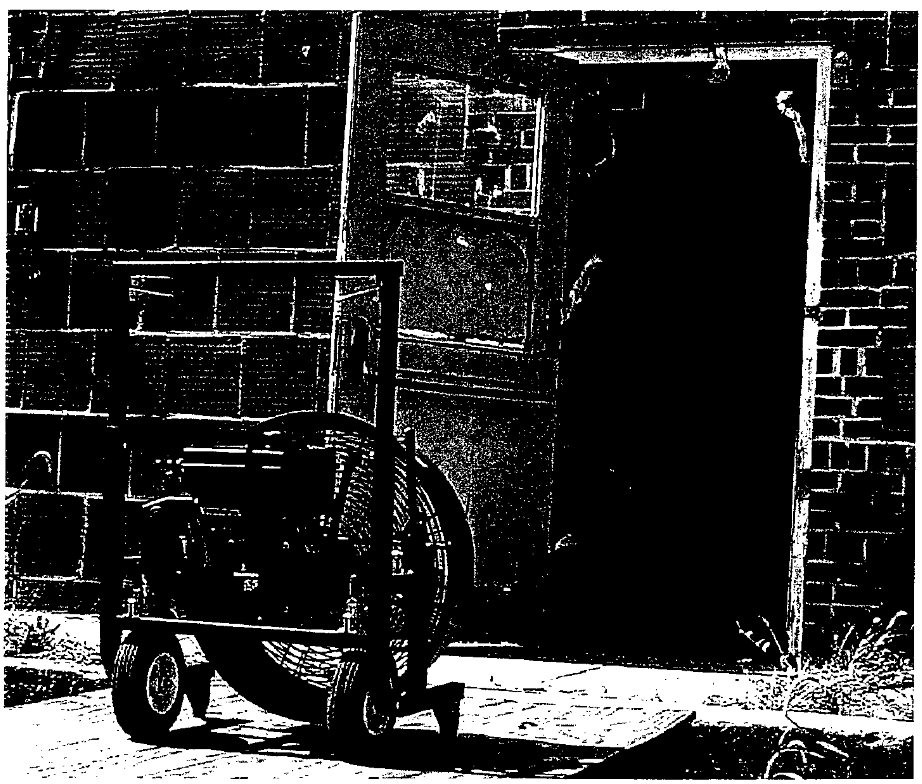

Figure 4. Test Series 2: One 20" Gasoline Fan

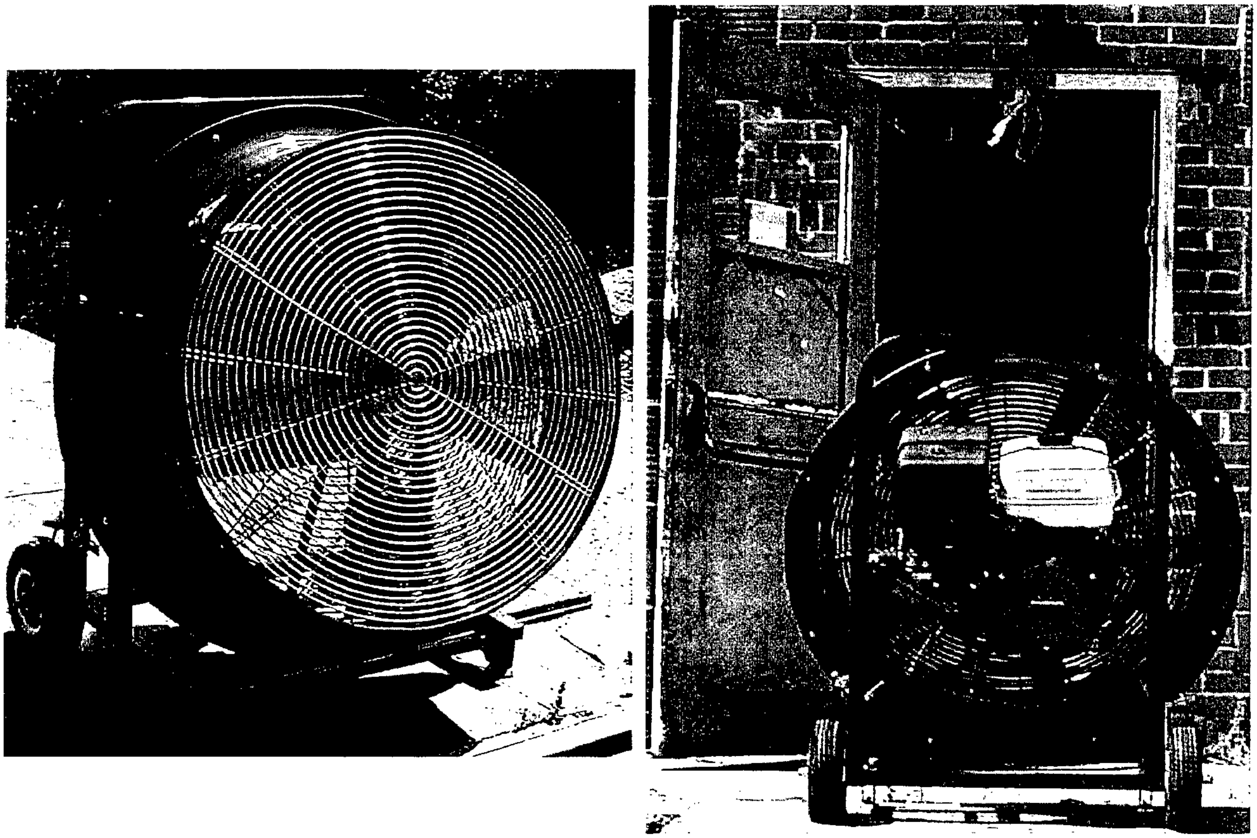

Figure 5. Test Series 3: Single 30" Gasoline Fan; Front View and in Test Position

Figure 6. Test Series 4: Two 20" Gasoline Fans in Series

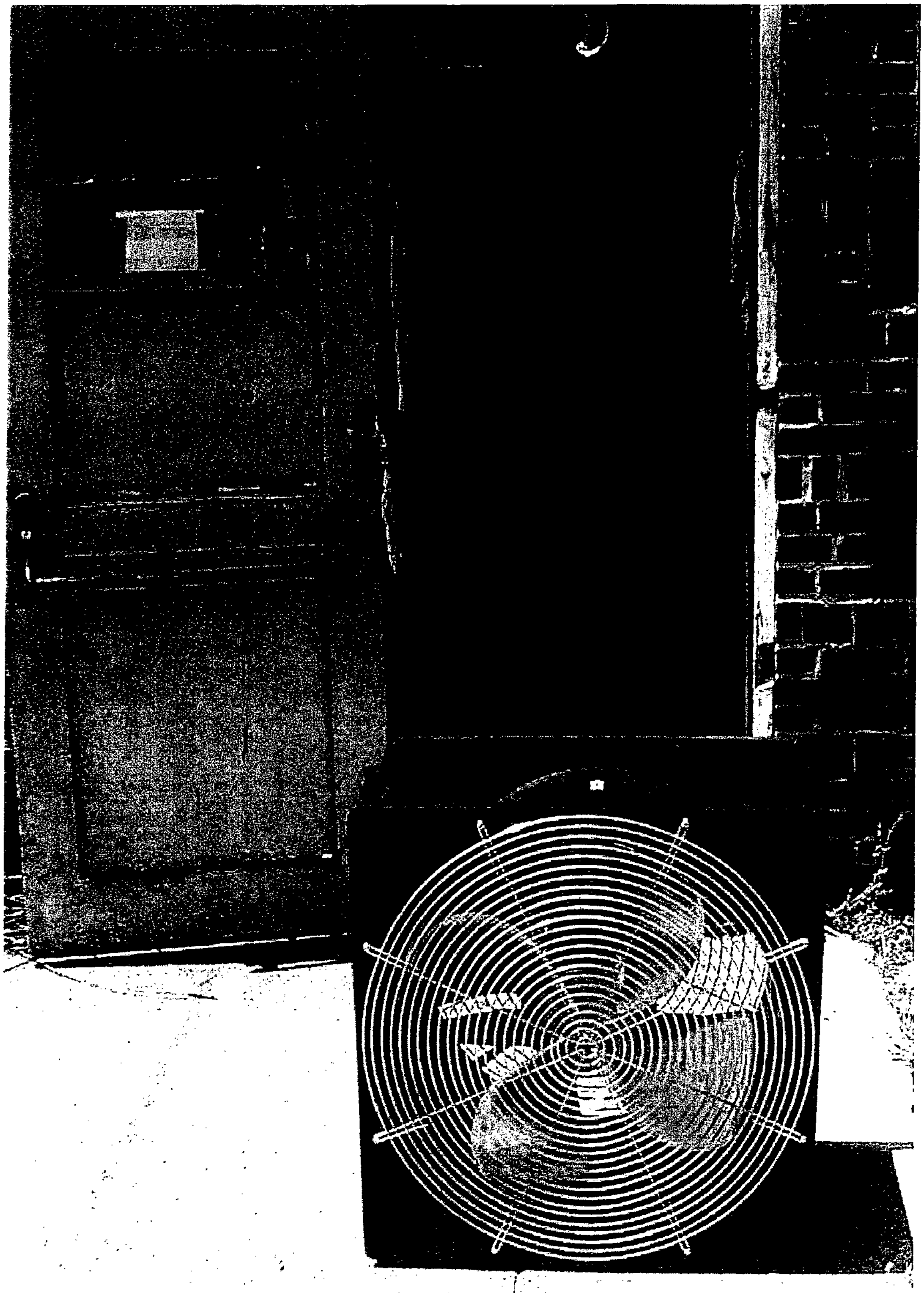

Figure 7. Test Series 5: One 24" Electric Fan, Positive Pressure Mode

Figure 8. Test Series 6: One 20" Gasoline Fan Tilted, Positive Pressure Mode

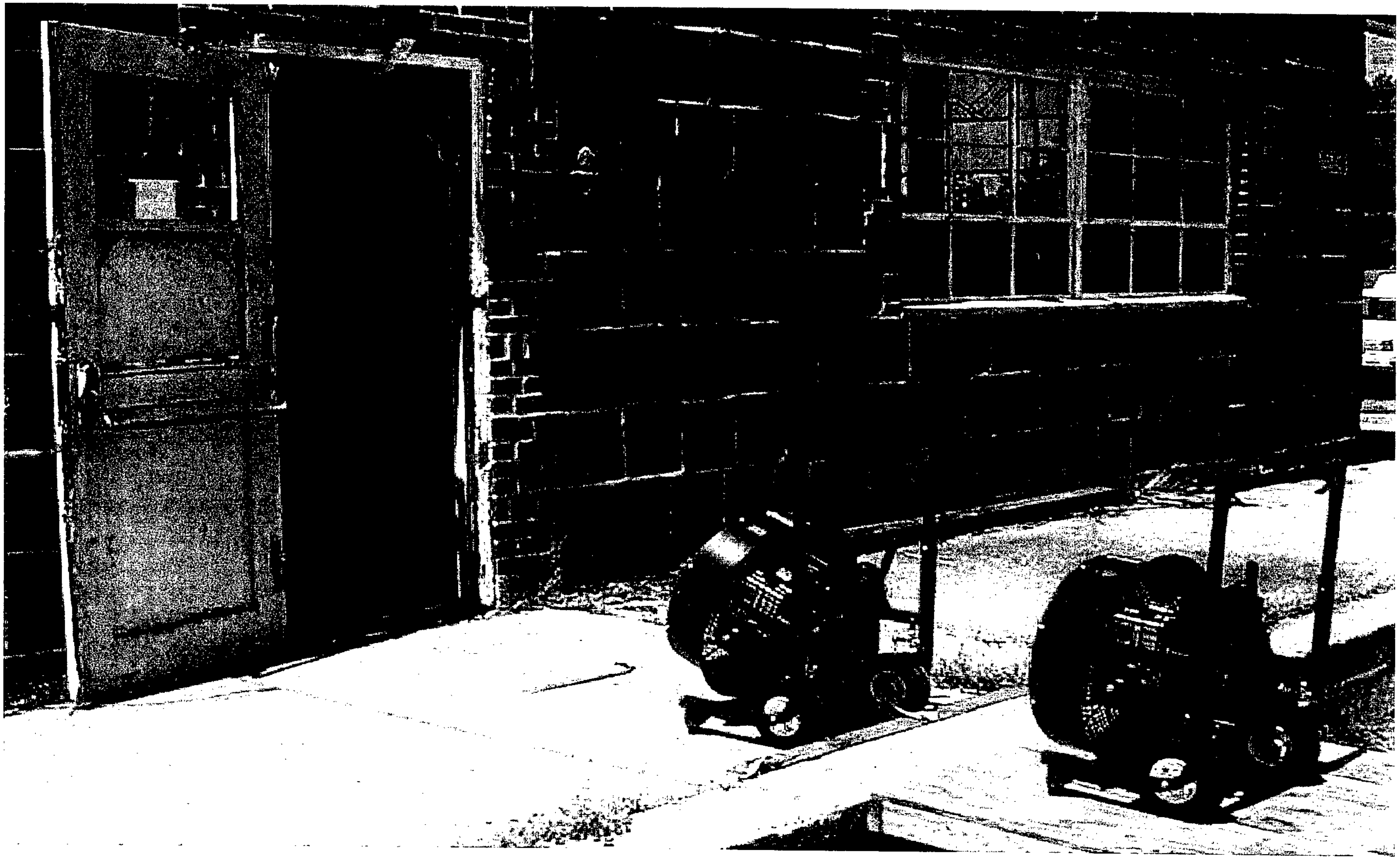

Figure 9. Test Series 7: Two 20"Gas Fans in Series, First Fan Tilted

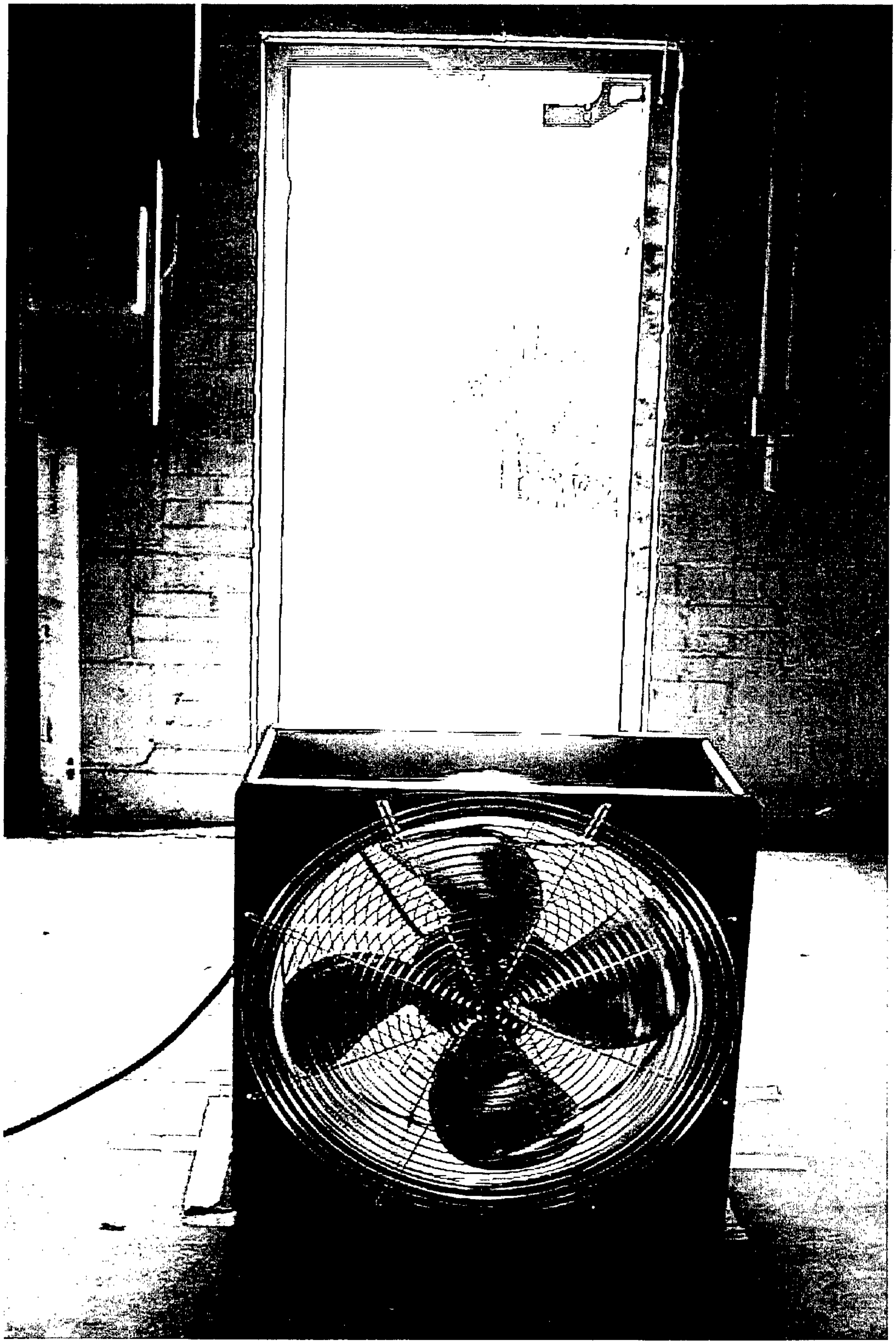

Figure 10. Test Series 8: One 24" Electric Fan, Negative Pressure Mode

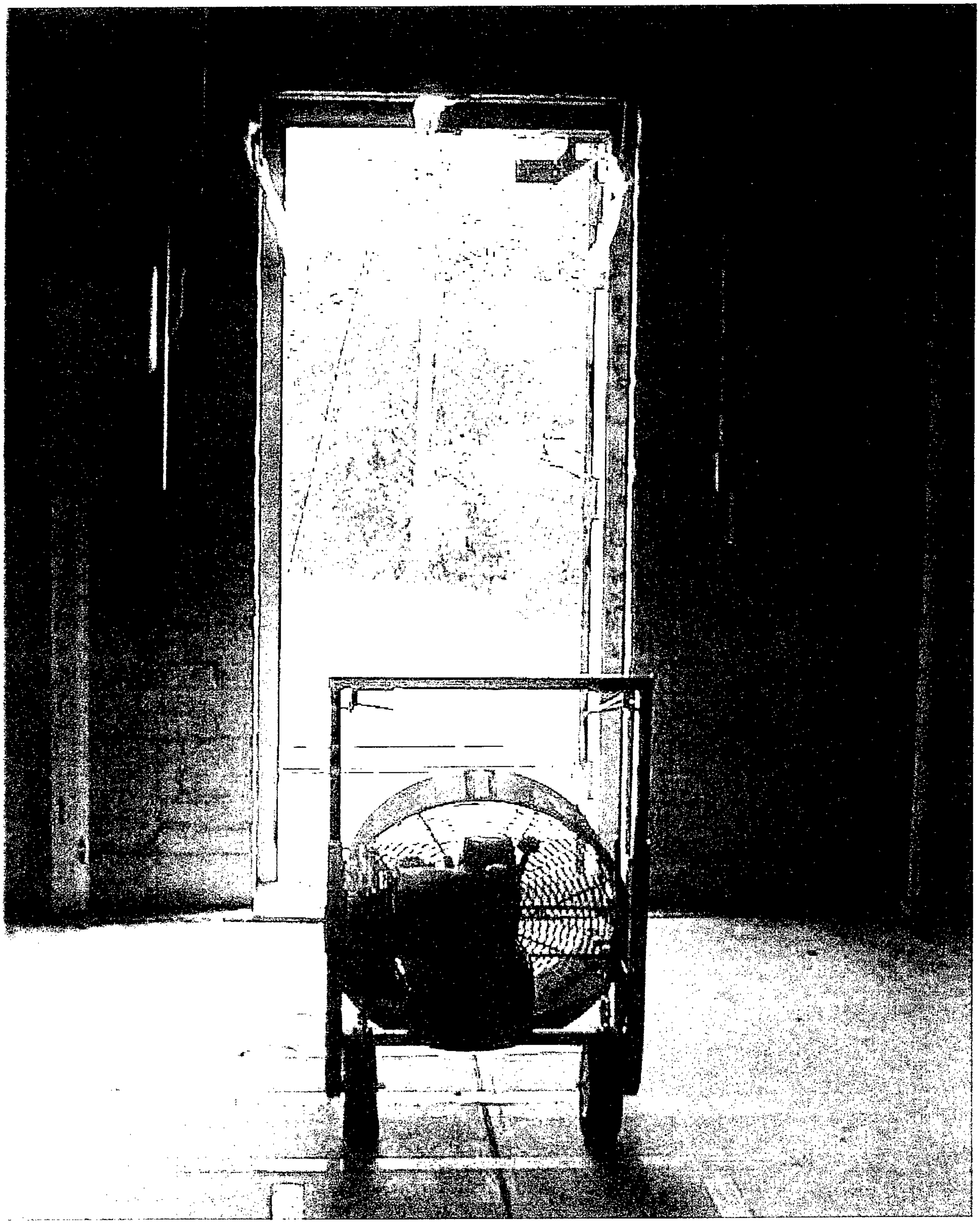

Figure 11. Test Series 9: One 20" Gasoline Fan Tilted, Negative Pressure Mode

The testing conducted in Phase 2 (the Rescue Mission) consisted of six 30-minute trials with a four-man rescue squad inside a building contaminated with Methyl Salicylate (MeS). The initial concentration of MeS inside the building was 8.0±0.8 ppm (50±5 mg/m^3). Only the double 16-inch Electric fan combination and the single 20-inch Gasoline fan were used; these fans were selected because they are most commonly used by firefighters across the country. After completing the Phase 1 testing, it was clear that bigger fans would provide more protection to firefighters in a live rescue scenario; however, it is unlikely that many fire companies across the country have bigger larger fans.

In the live rescue mission scenario, six trials were conducted. Two trials were performed with double 16-inch fans, three trials were performed with the single 20-inch Gasoline fan, and one trial was performed with no fans (baseline test). The double 16-inch fan was positioned at a location 10 feet, 4 inches from the door, in both its trials. In trials involving the single 20-inch Gasoline fan, the fan's position and tilt were varied, to observe differences in protection produced by different fan orientations. The three applied orientations are described below:

- The fan was level (to produce straight flow of air into the building), and placed 10 feet 4 inches from the door.
- The fan was tilted upward at an angle of 20° (so the airflow adequately covered the entire doorway), and placed 5 feet from the door. As determined through earlier testing, this location produced the greatest pressure inside the building.
- The fan was tilted upward at an angle of 20° and placed 12 feet 6 inches from the door. The firefighters selected this position by visually observing streamers taped to the doorframe, to indicate adequate coverage of airflow through the doorway.

Real-time concentrations of MeS were monitored in six different locations inside the building. One additional interior location, the interior Room 4, was also monitored during Phase 2 testing. One outside location, immediately outside the exit point of the building, was monitored with a Fourier Transform InfraRed (FTIR) device to measure the vapor concentration leaving the building. Sampling on each firefighters' body was performed at seventeen locations, using standard MIST procedures.

3. TEST EQUIPMENT AND PROCEDURES

3.1 <u>Phase 1, Ventilation Test Equipment and Procedures.</u>

A brief description of the ventilation test equipment and procedures is included in this section; for a more detailed explanation, the reader is referred to the ECBC Technical Report[2]. The basic procedures of the ventilation test were to fill the building and/or rooms with the SF_6 tracer gas and measure the concentration reduction over time, to determine the ventilation rate. Eight Miniature InfraRed Gas Analysers (MIRANs®) were used to monitor the SF_6 tracer gas concentration. Six were located inside the main building and two were located within interior rooms, as shown in Figure 2. All MIRANs® were calibrated with tracer gas standards before the testing. Concentration and time measurements were continuously recorded on a custom built Data Acquisition System (DAS).

Prior to Phase 1 testing, the optimum location (distance from the door) for the PPV fans during Phase 1 was found by varying the fan position and determining which position gave the maximum positive (or negative) pressure inside the building. An electronic pressure transducer was used to record the pressures inside the building as the fan's position was adjusted. The fan was first positioned at the door and then it was moved back (in one-foot increments) until the maximum pressure was obtained. This fan location was then used for all ventilation tests. The best distances for the PPV fans were between 9 feet and 10 feet four inches from the door, with the fans pointed straight in at the door (no tilting). When the fan's airflow direction was tilted, the optimum distance was 5 feet from the door. The optimum distance for the NPV mode (fans inside the building blowing air out) was 4 feet inside the door.

The baseline (natural) ventilation rate was measured first by filling the building and rooms with SF_6 gas and measuring the concentration as the building was naturally ventilated (through door, window, wall, and other structural leaks). The DAS was stopped after enough concentration readings were taken to adequately determine the natural ventilation rate of the building (usually around 2-3 hours).

After the baseline ventilation rate was determined, the building was refilled with SF_6 to determine the ventilation rate while the PPV fans were used. The interior rooms were closed during this part of the testing so no SF_6 would get in. The PPV fans were set in place and started; two windows on the opposite end of the building were opened up and used as the exit point for the fan's airflow. Concentration data was again recorded with the DAS while the building was ventilated by forced air from the PPV fan. During this portion of the ventilation testing, each test generally took 30 to 60 minutes.

During the NPV trials, fans were located inside the building, facing the open door. At the end of the building opposite the door, the opened windows, which were exit points during the PPV trials, were air entry points for the NPV trials. All other procedures remained the same.

The CO testing was performed after the last test using a single 20-inch gas fan (tilted upward at 20°) in both the positive pressure ventilation (PPV) mode and the negative pressure ventilation (NPV) mode. A Foxboro SAPPHIRE model MIRAN® was used to measure the concentration of CO inside the building at two locations during this testing. The PPV fan was started outside the building and operated for 15 minutes while the CO monitors recorded the concentrations inside the building. After this time, the fan was taken inside and operated in the NPV mode for an additional 20 minutes.

3.2 Phase 2, MIST Test Equipment and Procedures.

All MIST trials were conducted according to procedures used at the Edgewood MIST facility. These procedures follow the basic standard test procedures in TOP 10-2-022[3]. A brief outline of the procedures is presented here. The reader is again referred to the full ECBC Technical Report[2], for more details.

Sampling and dressing of test subjects was conducted in the MIST facility's Clean Room in Building E5354 in the Edgewood Area of Aberdeen Proving Ground, MD. The subjects were outfitted with Natick Passive Sampling Devices (PSDs), applied at seventeen locations on the body (see Figure 12 and Figure 13). These locations were chosen to correspond to locations contained in the Body Region Hazard Analysis (BRHA) model[4], which is used to evaluate the PPDF for the tested protective suit ensemble. After the samplers were in place and the subjects dressed in their Fire-Fighter Protective Ensembles (FFPE – PBI Bunker Gear), they were driven to Building E5840 to perform the rescue mission (see Figures 14 and 15).

A challenge concentration of MeS vapor was generated within the building with a hot-plate vapor generator. Mixing fans were used to circulate the vapors within the building. The initial concentration was raised to 8.0±0.8 ppm (50±5 mg/m^3) and held there by the data acquisition system (via remote control of the vapor generator) until the firefighters arrived at the building. Six locations inside the building were continuously monitored for MeS (for feedback control through the DAS) by six calibrated Foxboro Miniature InfraRed Gas Analysers (MIRAN®). All MIRAN® readings were recorded by the DAS and the average was used to control the vapor generator.

When the firefighters arrived at the building for the rescue mission, the PPV fans were set up and started by either the firefighters or the test technicians (see Figure 16). It should be noted that for test purposes it isn't necessary for firefighters to set up the PPV fans; the only requirement is that the fans be set up in the proper location. The firefighters then added a Quick-Fix to their Bunker Gear (see Figure 17) by applying duct tape to their ankle/boot closure, to their glove/wrist closure, and around the waist (in the same fashion as the 'Self-Taped' configuration used in the earlier MIST testing[1]). After the Quick-Fix for the Bunker Gear was in place the firefighters entered the building and performed the rescue mission (see Figures 18-20). Entry time was generally around 5 minutes after the PPV fans were started. Six 160-lb mannequins were rescued from the building within the 30-minute time set for the rescue mission. The firefighters then exited the building and rode back to the clean room area in Building E5354, where the patch samplers were removed and analyzed in the lab. The photographs shown below in Figures 12-20 show actual footage from one of the tests in the specific order that the procedures were performed.

4. METHOD OF ANALYSIS

4.1 Phase 1, Ventilation Rate of Improvement Analysis Methods.

The ventilation rate of the building was calculated by plotting the concentration decay over time (on a log/normal scale) inside the building and determining the slope of the concentration decay line. The Rate of Ventilation Improvement (RVI) between the natural (no PPV fans used) and the forced (with PPV) ventilation rates were calculated by dividing the forced rate by the natural rate at nominal wind speeds. The RVI is simply a multiplying factor of how many times faster the ventilation rate is during PPV fan use compared to not using PPV. All ventilation rate values were corrected to standard conditions of nominal wind speeds.

Figure 12. Subjects Having Patch Samplers Applied

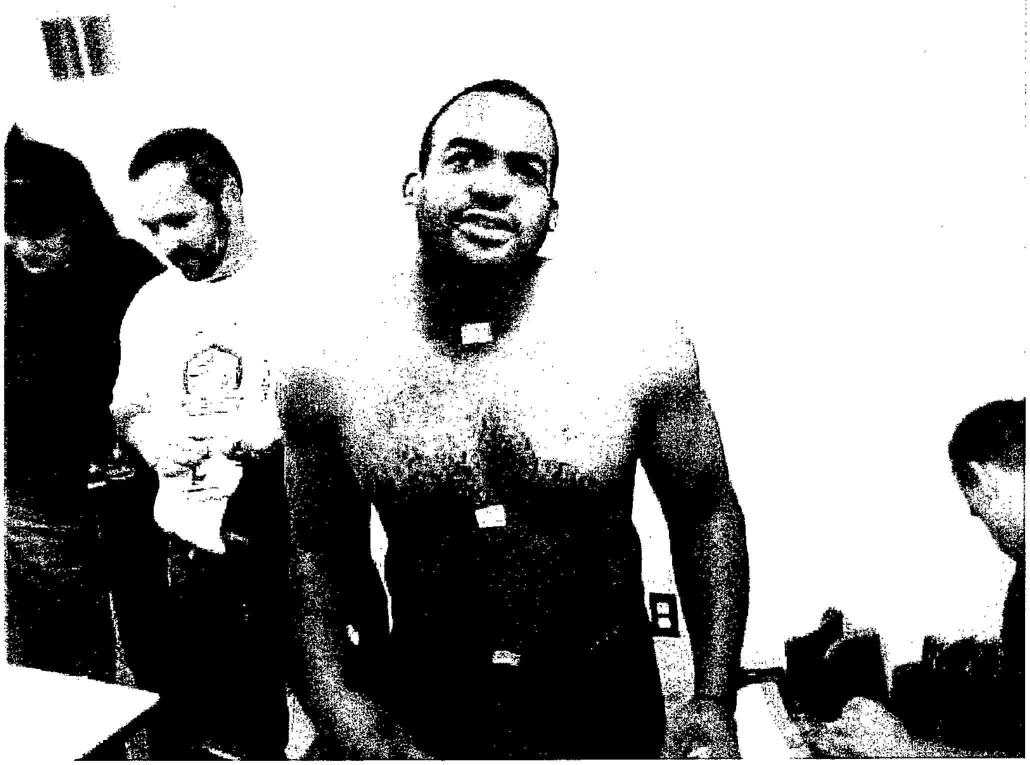

Figure 13. All Samplers In Place Before Dressing In Bunker Gear.

Figure 14. Firemen Finish Dressing Up In Bunker Gear

Figure 15. Transport to Rescue Building

Figure 16. Firefighter Setting Up PPV Fan Upon Arrival at Building Prior to Entry

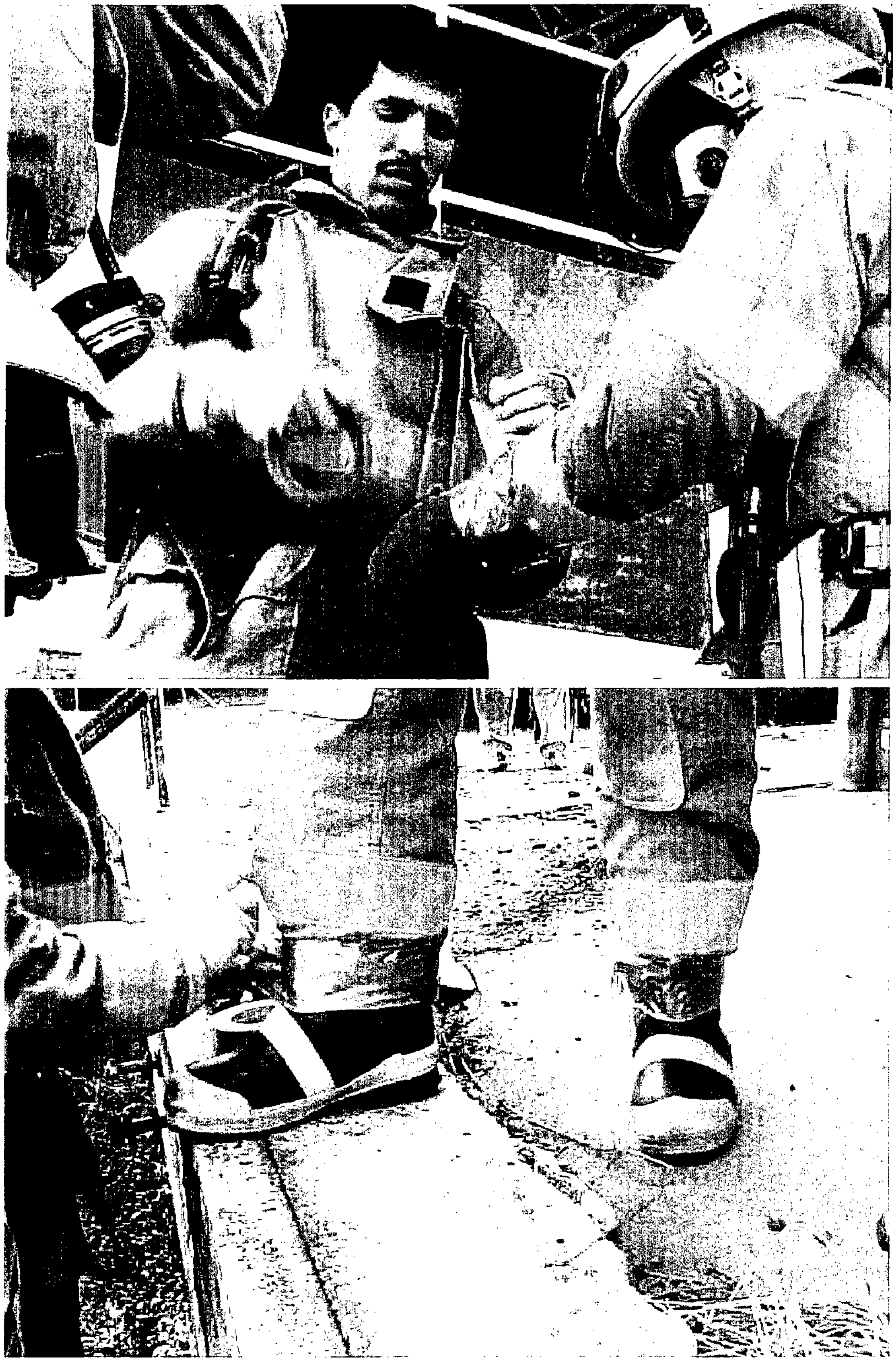

Figure 17. Firefighters Applying Duct Tape Quick-Fix to Their Bunker Gear

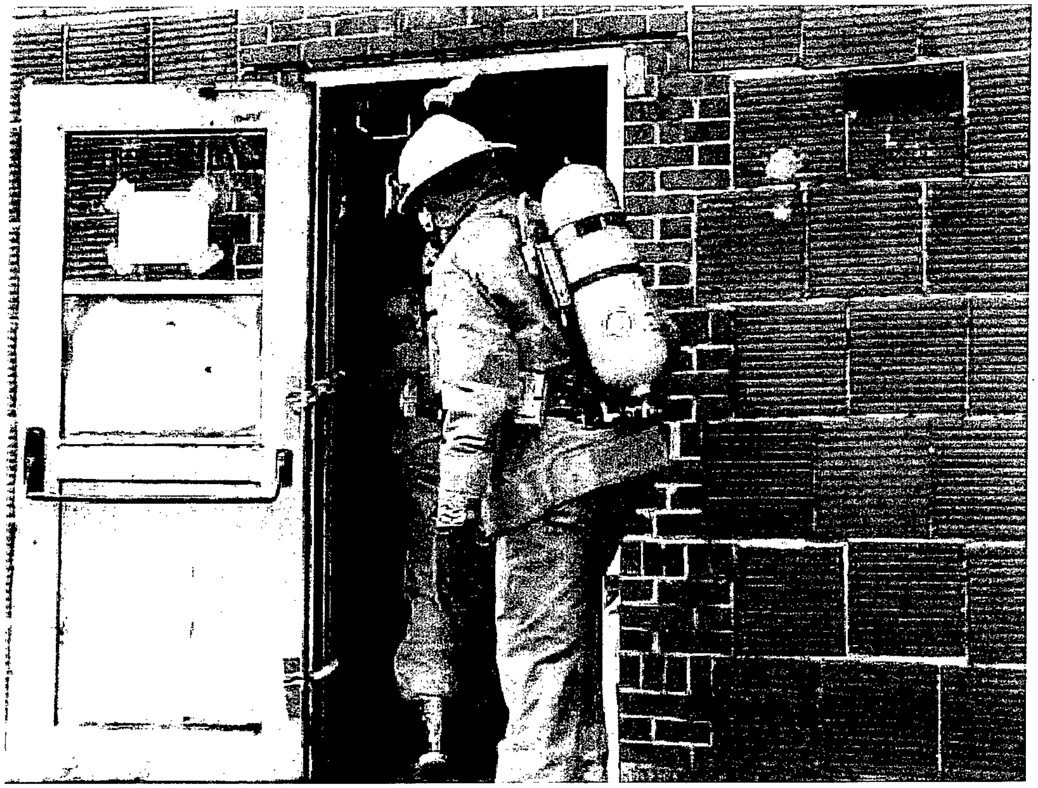

Figure 18. Entry To the Building

Figure 19. Victim Rescue Operations

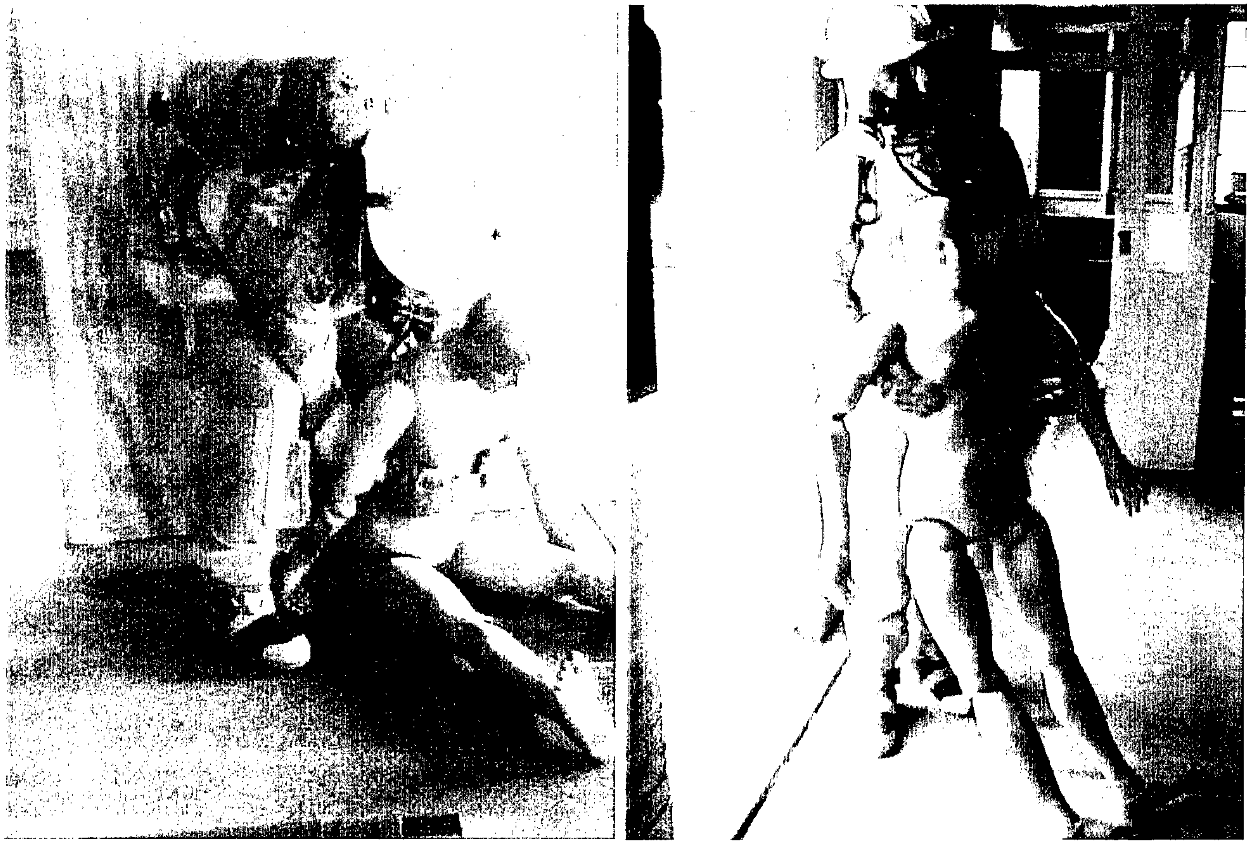

Figure 20. Under-Arm Drag Rescue Operation of 160 Pound Mannequin

4.2 Phase 2, Rescue Mission Analysis Methods.

The analysis methods used for the Rescue Mission portion of this testing consisted of the standard MIST analysis procedures using the Body Region Hazard Analysis (BRHA) method. The BRHA model is based upon historical test data of CWA[5] and pesticide[6] adsorption through human skin. The BRHA yields a Combined PPV/Bunker Gear PPDF for the complete firefighter ensemble worn during the Rescue Mission. The BRHA is also used to calculate other information on the dosage of nerve agent or mustard gas a firefighter can be exposed to (while wearing the protective ensemble in these conditions) before he will be affected. The reader is referred to the ECBC Technical Report[2] for a more complete description of the analysis details using the BRHA and for this additional dosage calculation information.

5. RESULTS AND DISCUSSION

5.1 Phase 1 Results, Ventilation Improvement With PPV Fans.

The results of the ventilation testing of the building using the different PPV fan configurations are listed in Table 2. The values included in this table are the percentage reduction in concentration within the first ten minutes, and the Rate of Ventilation Improvement (RVI)

(while using the fans). The RVI equals the ventilation rate using the PPV system divided by the normal ventilation rate of the building. The values listed in Table 2 are the average of all six

Table 2. Concentration Reductions and Rate of Ventilation Improvement (RVI)

Concentration Reduction after 10 min. of Use	Phase 1 Average Rate of Ventilation Improvement (RVI)	PPV Fan Configuration (distance measurements identify the location of the fan from the entrance door)
72%	43	One 30-inch Gas Fan at 9' from door, PPV Mode (see Figure 5)
71%	42	Two 20-inch Gas Fans in Series, 1st tilted 20° at 5' from door, 2nd straight at 9', PPV Mode (see Figure 9)
65%	37	Two 20-inch Gas Fans in Series (no tilting) at 3'6" and 9' from door, PPV Mode (see Figure 6)
64%	35	One 20-inch Gas Fan, tilted 20°, at 4' from door, NPV* Mode (see Figure 11)
63%	32	One 20-inch Gas Fan, tilted 20° at 5' from door, PPV Mode (see Figure 8)
57%	26	One 20-inch Gas Fan at 9' from door, PPV Mode (see Figure 4)
55%	26	One 24-inch Electric Fan at 9', PPV (see Figure 7)
50%	24	One 24-inch Electric Fan at 4', NPV (see Figure 10)
47%	22	Two 16-inch Electric Fans stacked at 10' 4", PPV (see Figure 3)

* NPV is Negative Pressure Ventilation where the fan is placed inside the building approximately 4 feet from an open doorway. Also the fan faces the doorway to blow air out the doorway (i.e., the doorway is the exit point for ventilation). Fans used in the Negative Pressure Ventilation (NPV) mode draw air out of the building instead of pushing it in, as is done in the PPV mode.

building areas monitored, and are also the average of all the tests performed for each PPV fan configuration used. These results show that the use of PPV fans can significantly reduce the concentration in building areas that have been contaminated with CWA (or other HazMat materials), within ten minutes. Fan configurations are arranged in this table in order of decreasing concentration reduction. Differences between the values in Table 2 illustrate the effectiveness of the different PPV fan configurations.

The best performance was with the 30-inch gas fan, which reduced the buildings' overall vapor concentration by 72% within the first 10 minutes of use. The second best performance was very close to this level (71% reduction); this result was obtained with the two 20-inch gas fans in series, with the first fan tilted upward 20° and the second fan straight. The next three values were the two 20-inch gas fans in series (no tilting) at 65%, and the single 20-inch gas fan that was tilted (both in the NPV and the PPV modes) at 64 and 63%, respectively. These values were so close and are a good example that shows how much improvement is seen just by tilting these fans to redirect the airflow - *one fan was almost as good as two because it was tilted to redirect the airflow.* The next value in the table confirms this conclusion, because the single 20-inch gas fan that wasn't tilted had a much lower value (than the fan that was tilted) of only

57%. Another important observation from these values is that the negative pressure ventilation mode tests were slightly better than the positive pressure tests for the 20-inch gas fan configuration when it was tilted. The electric fan test values for reduction of concentration were the lowest of all the fans tested, coming in at 55% for the 24-inch electric fan in the PPV mode, 50% for the same fan in the NPV mode, and 47% for the double 16-inch electric fans. The NPV mode values were slightly lower than the PPV mode values in this situation. However, even these values showed that the concentration was still significantly reduced within 10 minutes after putting the fans in operation. All tests using the same fan in both the negative and the positive pressure ventilation modes showed similar results for both modes. **The key concept exhibited by this data is that a PPV fan can purge the majority of chemical vapors from a building after 10 minutes of use.**

The rate of ventilation improvement (RVI) in the building (over the natural rate) for each PPV fan configuration tested during Phase 1 is also listed in Table 2. The RVI values followed the same trends seen with the concentration reduction values, with the larger 30-inch gas fan being best and the double 16-inch electric fan having the least effects on changing the natural ventilation rate of the building. For example, the forced air ventilation rate while using the 30-inch gas fan was 43 times faster than the natural ventilation rate. The ranking in order from best to worst performance was the same as the concentration reduction test ranking. General trends for all of this testing showed that:

- The larger fans had the best performance;
- Gas fans were better than electric fans;
- Tilting the fans to redirect their airflow improved the performance significantly
- Smaller, non-tilted fans were less effective; and
- Fans operated in the negative pressure ventilation mode produced results that were similar to fans run in the positive pressure ventilation mode.

Overall, the concentration reduction and improvement to the ventilation rates were proportional to the airflow rates of the fans, with higher airflow rates performing better than lower rates. Finally, the overall results in Table 2 clearly show that tilting gas fans produce maximum results. Only the first fan needs to be tilted when two gas fans are used in series.

The room infiltration rate was evaluated from the data to see if the PPV fans pushed the tracer gas into the interior rooms that were closed off to the rest of the building. The average infiltration rates of the interior closed rooms (rooms 2 and 4) were determined and the average rate from all tests is reported in Table 3. These values are ranked in order of the fan configuration that created the highest room infiltration rate to the lowest. This value is the average ventilation rate of both rooms that was caused by use of the PPV (or NPV) fans. It is clearly seen from all values in this table that the use of the PPV fans drove the tracer gas into the closed rooms. It should also be noted that when the fans were used in the negative pressure ventilation (NPV) mode the infiltration rates were negative; indicating that the tracer gas was removed from the rooms instead of being driven into the rooms by the fans (normal purging occurred with NPV). Figures 21 and 22 graphically show the difference in interior room concentrations when PPV versus NPV fans were used. Figure 21 shows how fast the concentrations in the rooms increased when the PPV fans were turned on. Figure 22 however, shows that there was no discernible rise

Table 3. Closed Room Infiltration Rates Caused by PPV Fans

Average Interior Room Infiltration Rate (Air Changes/Hour)	PPV Fan Configuration (distance measurements identify the location of the fan from the entrance door)
9.8	Two 20-inch Gas Fans in Series, 1st tilted 20° at 5' from door, 2nd straight at 9', PPV Mode (see Figure 9)
9.5	One 30-inch Gas Fan at 9' from door, PPV Mode (see Figure 5)
8.4	Two 20-inch Gas Fans in Series (no tilting) at 3'6" and 9' from door, PPV Mode (see Figure 6)
6.7	One 20-inch Gas Fan, tilted 20° at 5' from door, PPV Mode (see Figure 8)
5.5	One 24-inch Electric Fan at 9', PPV (see Figure 7)
3.2	Two 16-inch Electric Fans stacked at 10' 4", PPV (see Figure 3)
3.1	One 20-inch Gas Fan at 9' from door, PPV Mode (see Figure 4)
-0.6	One 24-inch Electric Fan at 4', NPV* (see Figure 10)
-1.1	One 20-inch Gas Fan, tilted 20°, at 4' from door, NPV Mode (see Figure 11)

* NPV is Negative Pressure Ventilation mode where the fan is placed inside the building blowing air out.

in concentration in the closed rooms of the building during the negative pressure ventilation tests. These results show that when PPV fans are used to clear vapors from a building that has interior closed rooms in it, the fans can drive the vapors into these rooms. Although the 30-inch gas fan did not have the highest rate, the general magnitude of the room infiltration rates was again proportional to the rated airflow of the fans. NVP was determined to be the preferred method for quick concentration reduction of CWA when interior rooms with closed doors exist in the building where people are present.

Carbon Monoxide (CO) monitors were used during the last day of testing to evaluate the amount of CO that accumulated in the building as a result of the use of the gas PPV fans. An additional test was conducted because concern arose that if a gasoline-driven fan was operating inside the building (for NPV), the CO concentration might get too high for victims. The 20-inch gas fan (tilted) was used during this test in both the positive (PPV), and the negative (NPV) pressure ventilation modes. Concentrations were measured in the center of the building and near the door where the NPV fan was operating. The CO concentration during the PPV portion of this test went up immediately after the fan was started and continued to rise throughout the 15-minute period that is was operated (see Table 4 below). The net increase in CO concentration during the PPV portion of the test was approximately 6½ ppm (well below the TWA limit of 35 ppm). The fan was then stopped and brought inside for the negative pressure ventilation (NPV) portion of the test. During this time, the CO concentration decreased. Table 4 shows that the level of CO during use of the gas NPV fan inside the building decreased between 5 and 7 ppm. In general, NVP mode operation of the fans blows CO out of the building, while PPV mode operation of the fans blows CO into the building.

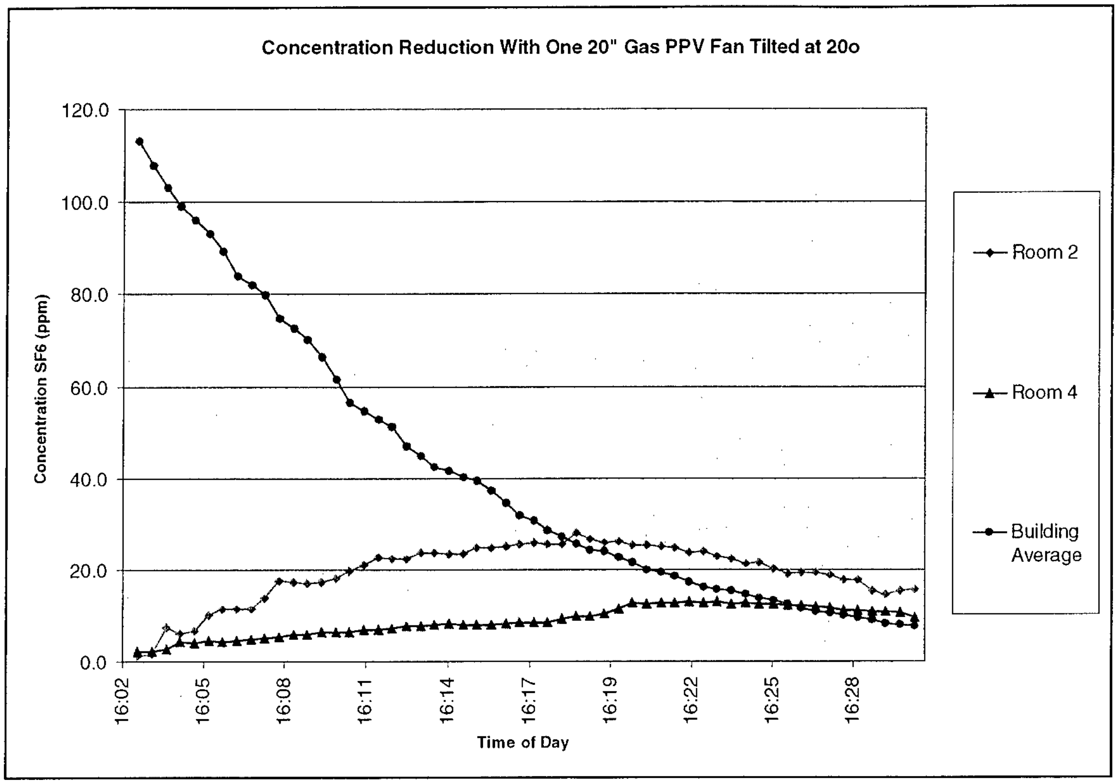

Figure 21. Concentration Profile Using Positive Pressure Ventilation (PPV - Test 4b)

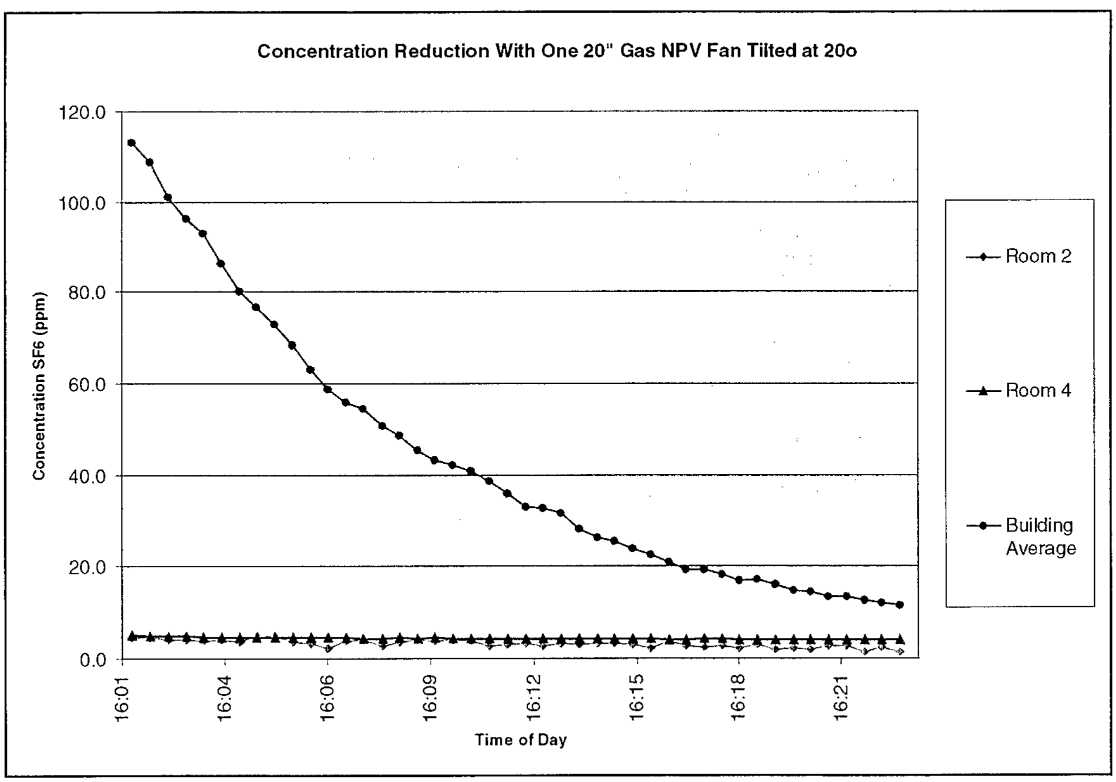

Figure 22. Concentration Profile Using Negative Pressure Ventilation (NPV - Test 7b)

Table 4. CO Concentrations inside the Building During Use of 20" Gas Fan

PPV Mode	CO Concentration (ppm) Middle of Bldg	CO Concentration (ppm) Near Door (and fan)
Starting Concentration:	0.000	2.124
Ending Concentration (fan run 15 min):	6.789	8.634
Net CO Concentration *Increase*:	**6.789**	**6.510**

NPV Mode	CO Concentration (ppm) Middle of Bldg	CO Concentration (ppm) Near Door (and fan)
Starting Concentration:	5.935	7.998
Ending Concentration (fan run 20 min):	0.484	1.174
Net CO Concentration *Decrease*:	**5.451**	**6.824**

5.2 Phase 2 Results, Rescue Scenario Mission.

During Phase 2 testing the firefighters used the PPV fans to reduce the hazard inside the building before performing a live rescue mission. The 20-inch gas fan and two 16-inch stacked electric fans were selected for Phase 2 testing because they are most commonly available across the Fire Service. The results of the MIST Body Region Hazard Analysis (BRHA) are summarized in Table 5 below. This data was analyzed to determine the average values of the Combined PPV/Bunker Gear PPDFs of all the test subjects during each test. Table 5 lists the conditions of each test and the Combined PPV/Bunker Gear PPDF that the PPV fans and firefighters' protective ensemble provided. These values correspond to the protection afforded against percutaneous adsorption of vapor through the skin only. These values are not indicators of the respiratory protection offered by the SCBA, which is certified by the manufacturer to be at a value equal to, or greater than 10,000.

Table 5. Rate of Improvement (ROI) for Combined PPV/Bunker Gear PPDFs

Test	PPV Fan Configuration Used	Combined PPV & Bunker Gear PPDF	Phase 2 Rate Of Improvement (ROI)
3	No PPV Fans (baseline)	21	1
1	One 20-inch Gas Fan at 10' 4", fan straight	73	3
4	Two 16-inch Electric Fans at 10' 4", fan straight	138	7
2	Two 16-inch Electric Fans at 10' 4", fan straight	203	10
6	One 20-inch Gasoline Fan at 12' 6", fan tilted 20°	255	12
5	One 20-inch Gasoline Fan at 5', fan tilted 20°	564	27

The results of Phase 2 testing showed that the firefighters' protection was increased tremendously when the PPV fans were used. The baseline Bunker Gear PPDF (without using PPV fans) was an average of 21. The best results produced an average overall PPDF of 564 when the single 20-inch gas fan was used in the tilted mode at the predetermined optimal fan location (5

feet) that yielded the best pressurization of the building. Test 6 was conducted with the same fan positioned by the firefighter visually with streamers taped on the doorway. This resulted in about half the protection (PPDF of 255) as the optimal fan location provided.

Also, during test 4 the electric fans were inadvertently not started 5 minutes prior to the firefighters entry, as was done in all the other tests. Comparing to test 2 where the electric fans were started prior to the firefighters entry demonstrates how starting the PPV fans for just 5 minutes before entry can improve protection significantly (average overall PPDF of 203 versus 138). **In summary, all of these test measurements show that the use of PPV fans will improve the protection of firefighters to a great degree if they must perform rescue missions in buildings that have been exposed to CWA vapor contamination.**

Table 5 also lists the rate of improvement (ROI) obtained while using the PPV fans compared to the baseline test where no fan was used. The Rate of Improvement (ROI) determines how much the use of PPV fans improves the firefighters' protection. The ROI for each test was determined by comparing the Combined PPV/Bunker Gear PPDF (for that test) with the baseline Bunker Gear PPDF (i.e., the test when no PPV fans were used). The ROIs listed in Table 5 were calculated by dividing the Combined PPV/Bunker Gear PPDF for each fan configuration by 21 (baseline Bunker Gear PPDF when no PPV fans were used). The ROI is simply a multiplying factor of how many times greater the firefighters' protection is during PPV fan use compared to not using PPV. The ROI results in Table 5 show that for the fans tested during Phase 2 the best improvement provided the firefighters 27 times as much protection against CW vapors as opposed to not using PPV. Even the least improvement still provided the firefighters 3 times as much protection as opposed to not using PPV.

Again the best improvement (an ROI of 27) was obtained when the 20-inch gas fan (tilted at 20°) was used at the pre-determined position (5 feet from the door) where the maximum overpressure in the building was obtained. This fan position was determined experimentally with pressure gauges before the testing began. The second best ROI of 12 was obtained when the same gas fan configuration was used at a different position (it was placed at 12' 6" from the door). The position of the fan in this test was determined visually by the firefighters through use of streamers taped on the door. This demonstrates that additional chemical protection can be gained by positioning PPV fans at the optimal distance from the entrance door (i.e., the protection is doubled by doing so in this case). If available, hand-held pressure gauges can be used to determine better fan locations than visual streamers; this will provide better protection to the firefighters.

The simulant (MeS) used in these tests has a strong wintergreen smell and was therefore easy to track some relative distances from the building. This scent could be detected easily at distances of 5 to 10 feet from the building, and in most areas within 30 to 50 feet near the exit point of the air from the building. This smell was generally not recognized at distances greater than 100 feet from the building. The odor threshold for MeS is very low (lower than harmful concentration levels for most chemical agents). However, this detection method (sense of smell) is not a quantitative method so there may have been MeS present at further distances. The evacuation distance must be determined by the Incident Commander (IC) in charge at a site of terrorist activity, and would best be made through use of chemical agent detectors capable of very low level detection of specific chemical agents.

If low level chemical agent detectors are not available, more specific guidelines for evacuation distances are available in the North American Emergency Response Guidebook[7], NAERG96. Figure 23 shows a diagram of the initial isolation distance and downwind evacuation distances that are recommended for spills. The Initial Isolation Zone distance from the NAERG96 is 700 ft for toxic liquids and 30-80 ft for infectious materials. The Downwind Distances from the NAERG96 are 1.2 miles during the day and 5.5 miles during the night for spills of toxic liquids.

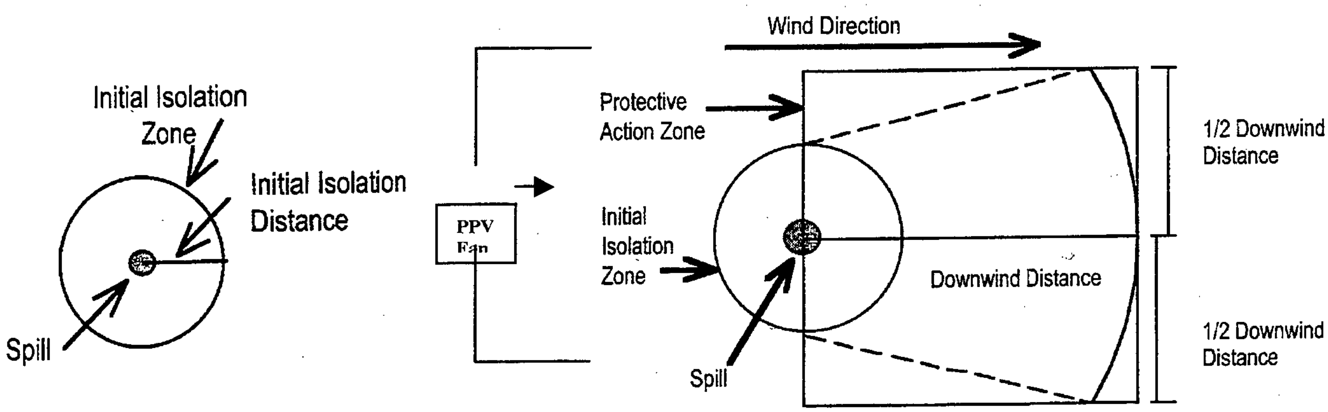

Figure 23. Initial Isolation Zone and Downwind Evacuation Distances for Spills

6. CONCLUSIONS AND RECOMMENDATIONS

The use of PPV fans at a site of terrorist activity where chemicals have been disseminated will significantly reduce the vapor levels inside the building and increase the safety of first responders who must enter the building to effect rescue operations. The most significant conclusions are listed below:

- Rates of Ventilation Improvement (RVIs) ranged from 22 to 43 times the natural ventilation rate. The best improvements were seen when the 30-inch gas fan or the two 20-inch gas fans in series (first tilted, second straight) were used.

- The percentage concentration reduction obtained in the building after the PPV fans were put in use for only ten minutes ranged from 47% to 72% of the initial concentration.

- Phase 1 testing showed that using fans in the NPV orientation is good because concentrations did not rise inside interior rooms with closed doors as it did in the PPV orientation. Additionally, the fan's performance did not degrade significantly in the NPV orientation compared to the PPV orientation.

- The overall results of the MIST testing during Phase 2 showed tremendous improvements in the protection afforded to the firefighters through use of the PPV fans to clear the vapors from the building. Of the two fans tested during Phase 2 the best results were obtained with the single standard 20-inch gas PPV fan used in the tilted mode.

- Only the 20-inch gas and the double 16-inch electric fans were used during the Phase 2 live rescue mission tests (these are the fans that most firefighters have). If more efficient fans are used (30-inch gas or double 20-inch gas fans), the improvement to the firefighters' safety will be increased even more.

- Fan efficiency and chemical protection improved significantly when the optimal fan location (distance from the door) was used. The optimal fan location could only be determined with pressure gauges; using just the visual streamers was not good enough.

It is recommended that a hand-held pressure gauge be used by firefighters when determining the optimum distance from entry doors to place PPV fans in service at a building. Optimal distance is the fan location where the measured pressure inside the building is the greatest. Two sources for portable pressure gauges are Dwyer Instruments, Inc., and Omega Technologies Company. Any source for portable pressure gauges would be sufficient as long as the instrument measures very low-pressure readings; a range of 0 to 1 inches water gauge (iwg) or lower is desired. However, visual verification with streamers still provides a rough estimate for PPV location if portable pressure gauges are not available.

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